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sensors worldwide

SMARTLEVEL Technology

Accurate point level detection

White Paper

White Paper

Liquid-level applications with enhanced capacitive sensor technology

Accurate point level detection

Executive Summary

This document identifies key issues experienced by manufacturers of equipment and end users regarding the detection of liquid levels with capacitive proximity sensors. It examines sensing methods that will improve processes while assuring reliable and dependable non-invasive liquid level detection.

Important factors that affect the total cost of ownership for liquid level sensors are:

Time for assembly and setup

Time allocated to install and configure each individual sensor

Engineering effort for application

The time it takes to integrate and make the individual sensor solution function properly

Long-term reliability

Sensors must perform flawlessly and tolerate operational imbalances or imperfections.

Confined Mounting Space

Limits the sensor housing and technology options when integrating the sensors into equipment.

In addition to application specific challenges and external general requirements for sensors, traditional capacitive technology itself imposes pitfalls for robust and long-term stable operation.

False positive triggering

A result of material buildup, condensation or humidity, or foaming

Changing material compositions

The target or container material might require frequent sensor recalibration

Balluff, a worldwide manufacturer of automation solutions, developed a patented new approach to capacitive sensing technology to address these challenges in capacitive sensing technology. This paper will describe capacitive non-invasive sensing technologies and their related applications.

Capacitive Sensors in Liquid Level Detection Applications

In liquid level sensing applications, capacitive sensors can be mounted directly in contact with the medium or indirectly with no contact to the medium.

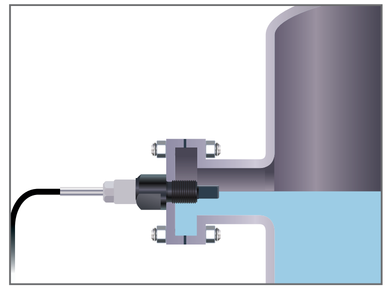


Figure 1: Direct sensing mount

Containers made of metal or very thick non-metallic tank walls (more than 1") typically require mounting the sensor in direct contact with the medium (Fig. 1). In some instances, a by-pass tube or a sights glass is used, and the senor detects the level through the wall of the non-metallic tube (Fig. 2).

Figure 2: Indirect sensing mount

The direct mounting method could simplify sensor selection and setup since the sensor only has to sense the medium or target material properties. Nonetheless, this approach imposes certain drawbacks, such as costs for mounting and sealing the sensor as well as the need to consider the material compatibility between the sensor and the medium. Corrosive acids, for example, might require a more expensive exotic housing material.

Table 1.1: Chemical Compatibility Chart

	Acids	Alkaline	Solvents	Alcohol	Fuel
PBT Polybutyleneterephtalate	P	P	E	G	G
PVC Polyvinylchloride	G	G	P	F	P
POM Polyoxymethylene	P	P	E	F	G
PTFE Polytetrafluoroethylene	E	E	E	E	G
PP Polypropylene	G	E	P	G	F
PSU Polysulphone	E	E	G	G	P

E = Excellent **G = Good** **F = Fair** **P = Poor**

The preferred approach is indirectly mounting the capacitive sensor flush against the non-metallic wall to detect the target material non-invasively through the container wall (Fig. 2). The advantages for this approach are obvious and represent a major influence to specify capacitive sensors. The container wall does not have to be penetrated, which leaves the level sensor flexible and interchangeable in the application. Avoiding direct contact with the target material also reduces the chances of product contamination, leaks, and other sources of risk to personnel and the environment.

The target material also has relevance in the sensor selection process. Medical and semiconductor applications involve mostly water-based reagents, process fluids, acids, as well as different bodily fluids. Fortunately, high conductivity levels and therefore high relative dielectric constants are common characteristics among all these liquids. This is why the primary advantages of capacitive sensors lies in non-invasive liquid level detection, namely by creating a large measurement delta between the low dielectric container walls (see relative dielectric constants in table 1) and the target material with high dielectric properties.

At the same time, highly conductive liquids could impose a threat to the application. This is because smaller physical amounts of material have a larger impact on the capacitive sensor with increasing conductivity values, increasing the risk of false triggering on foam or adherence to the inside or outside wall.

Table 1.2: Selected Dielectric Constants

Material	Dielectric Constant		Material	Dielectric Constant
Air	1.0		Glass	3.1 - 10
Oil	4 - 5		Polyamide	2.5
Water	48 - 88		Polycarbonate	2.9
Aqueous Solutions	50 - 80		Polypropylene	2.3
			Polyvinyl Chloride	3.1
Acetone	19.5		PTFE	2.0
Alcohol, Isopropyl	18.3		Rubber	2.5 - 35
Ethanol	24			
Glycerin	47			
Hydrochloric Acid	4.6			
Hydrogen Peroxide	86			
Chlorine, liquid	2.0			

In order to see the full capability of capacitive sensors in liquid level applications, one has to understand the basic sensing principle of capacitive sensors.

A Basic Review of Standard Capacitive Sensing Technology

Capacitive sensors detect an object - or in this case a liquid - by sensing a change in an electrostatic field. Located in the face of the sensor are two metal plates that act as the plates of a capacitor. When power is applied and no target is present, the capacitance is low and the internal oscillator amplitude is low. As a target enters the electrostatic field, the capacitance increases causing the oscillator frequency to increase until a threshold is reached changing the state of the output. The threshold of the capacitive sensor is adjustable via a potentiometer, which in turn adjusts the sensing distance.

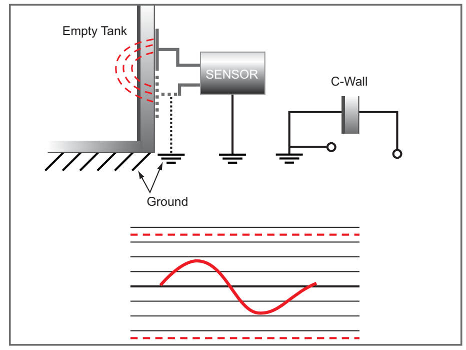


Figure 3: Standard capacitive sensor oscillator output below switching condition.

The rated sensing distance of a standard capacitive sensor is based on a standard mild steel target that is at least equal to the size of the sensor face and one millimeter thick. The effective sensing distance of a capacitive sensor is determined by three factors. First is the size of the sensing face of the sensor, the larger the face the greater the sensing distance. Second is the surface area of the target, the area should be equal to or larger than the face of the sensor. Third is the dielectric strength or dielectric constant of the target material. All materials have a dielectric strength, the higher the value the easier to detect the object or the greater the distance (see relative dielectric constants in table 1). The dielectric constant could be analogous to a reduction factor. Other factors that can influence the sensing distance to a lesser degree include temperature, frequency, and humidity.

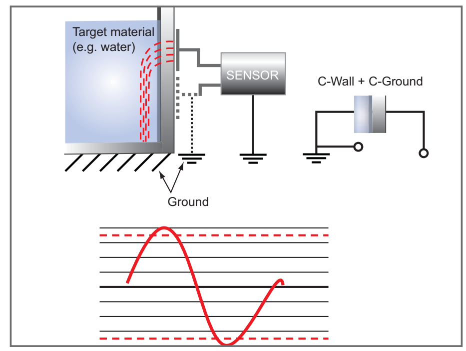


Figure 4: Standard capacitive sensor oscillator output above switching condition.

In order to get reliable and dependable sensing results, the user must manually adjust the sensor's sensitivity or threshold by means of a potentiometer. In an indirect level detection application, a capacitive sensor would be adjusted to the point where it ignores the container wall but reliably detects the capacitance change caused by the changing level of the target material. Typically, a standard capacitive sensor can be adjusted to disregard a wall thickness of approximately 4mm. In addition, the dielectric strength or constant of the target medium must be higher than the container wall for reliable detection of the liquid level.

Potential Sources of Failure with Standard Capacitive Sensors

Capacitive sensors detect any changes in their electrostatic sensing field. This includes not only the target material itself, but also application-induced influences such as condensation, foam or temporary or permanent material build-up. High viscosity fluids can cause extensive delays in the accurate point-level detection or cause complete failure due to the inability of a capacitive sensor to compensate for material adhering to the container walls. In cases of low conductivity fluids such as water or deionized water and relatively thin container walls, the user might be able to compensate for these sources of failure. Potential material build-up or condensation can be compensated for by adjusting the sensitivity of the sensor, cleaning of the container, or employing additional mechanical measures.

This strategy works only if the fluid conductivity stays low and no other additional influencing factors like temperature, material buildup, or filming challenge the sensor. Cleaning fluids like sodium hydrochloride, hydrochloric acid, chemical reagents, or saline solutions have very high electrical conductivity values, which cause standard capacitive sensors to false trigger on even the thinnest films or adherence. The same applies for body fluids such as blood, or concentrated acids or alkaline.

Challenges of this type of application are not obvious. This is especially true when the sensors performed well in the initial design phase but fail in the field for no obvious reason. An example of this would be when the sensors on the equipment are setup with deionized water ;however, the final process requires some type of acid. Difficult and time-consuming setup procedures and unstable applications requiring frequent readjustment are the primary reasons why capacitive level sensors have been historically avoided in certain applications.

Enhanced Capacitive Technology

A perfect capacitive sensor for non-invasive level detection applications would not require any user adjustment after the initial setup process. It would detect any type of target material through any non-metallic type of tank wall while automatically compensating for material build-up, condensation, and foam.

This enhanced sensing technology helps the sensors to distinguish effectively between true liquid levels and possible interferences caused by condensation, material build-up, or foaming fluids. While ignoring these interferences, the sensors would still detect the relative change in capacitance caused by the target object but use additional factors to evaluate the validity of the measurement taken before changing state.

These sensors are fundamentally insensitive to any non-conductive material like plastic or glass, which allows them to be utilized in non-invasive level applications. The enhanced capacitive sensors only limitation is it requires electrically conductive fluid materials with a dipole characteristic such as water to operate properly.

SMART*LEVEL*™ Technology

SmartLevel™ sensors work with a high-frequency oscillator whose amplitude is directly correlated with the capacitance change between the two independently acting sensing electrodes. Each electrode independently tries to force itself into a balanced state. That is the reason why the sensor independently measures the capacitance of the container wall without ground reference and the capacitance of the conductivity of the liquid with ground reference (contrary to standard capacitive sensors).

Without having target material introduced into the sensor's field, the amplitude of the oscillator is at a nominal state (Fig. 5). An empty container wall creates a capacitance change: the amplitude rises above the nominal level; however, it will never lead to a valid switching condition unlike a standard capacitive sensor (Fig. 6). As a conductive liquid rises in the

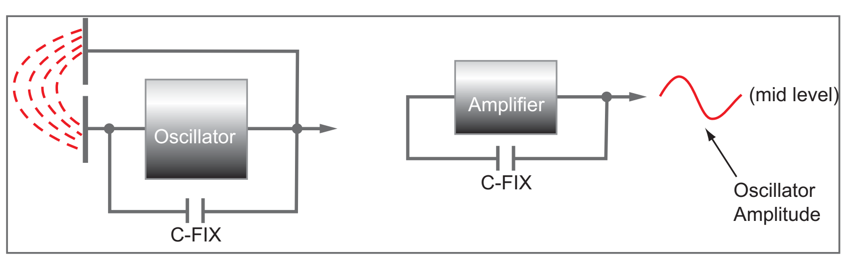


Figure 5: Enhanced capacitive sensor detection schematics – no target present.

container, a second, much higher capacitance with respect to ground will be created. This second capacitance, being significantly higher than that of the container wall, affects the oscillation inversely to the capacitive effect of the wall and pulls the amplitude down to 0V, triggering the sensors output (Fig. 7).

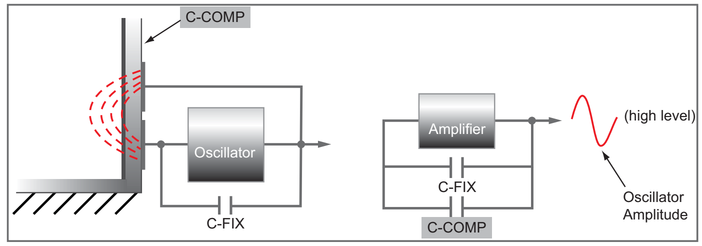


Figure 6: Enhanced capacitive sensor detection schematics – automatic tank wall compensation

The key advancement is that SmartLevel sensors compensate for differing conditions by operating at a field frequency of 6.5 MHz, which is approximately seven-times higher than that of an ordinary capacitive sensor. This high AC frequency reduces the reactance segment of the impedance between the active sensor surface and the material build-up, allowing the sensor to detect true levels without interference.

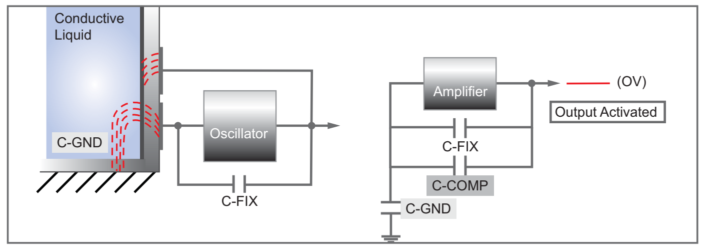


Figure 7: Enhanced capacitive sensor detection schematics – liquid level presence detection

SmartLevel sensors provide cost-effective, reliable point-level monitoring for a wide array of medical, biotechnology, life sciences, semiconductor processes, and other manufacturing processes and procedures. Balluff offers this technology exclusively in a wide array of sensor configurations all aimed at accommodating the full breadth of science and industry's most stringent application-specific level monitoring requirements. SmartLevel capacitive sensing technology brings considerable advantages to the area of liquid level detection, not only offering alternative machine designs, but also reduced assembly time for the machine builder as well as drastically reduced field service liability.

Machine designers now have the flexibility to non-invasively detect almost any type of liquid through plastic, glass tubes, or other non-metallic container walls, reducing mechanical adaption effort and fabrication costs. Discrete indication tasks like fluid presence detection in reagent supply lines, reagent bottle level feedback, chemical levels and waste container overfill prevention are now a distinct competence for capacitive sensors. Reagents and waste liquids are composed of different formulas depending from customer to customer or and even sometimes the end user. The sensing technology has to be versatile enough to compensate automatically for changing environmental or media conditions within high tolerance limits.

Applications that require precision and an extraordinary amount of reliability, such as blood presence detection in cardiovascular instruments or hemodialysis instruments, medical, pharmaceutical machine builders, equipment builders for semiconductor processes can rely now on SmartLevel capacitive sensing technology.

SMART*LEVEL*™ solves more level detection applications

- Compensates automatically for humidity, foam, and material build-up
- Senses liquids through glass or plastic walls up to 10mm thick
- Detects aqueous and highly-conductive liquids reliably

Reduces costs

- Eliminates routine cleaning maintenance
- Self-adjusts to most applications after initial setup
- Simplifies mounting and installation efforts

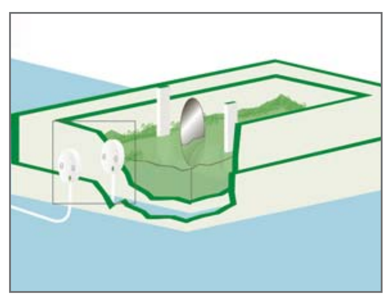
SmartLevel capacitive sensors are available in three families. Figure 8 shows a basic range comparison of the SmartLevel families and a standard capacitive.

BCS Standard up to approx. 0.7 mS	**SMART***LEVEL* 15 approx. 0.7...15 mS	**SMART***LEVEL* 50 approx. 15...50 mS	**SMART***LEVEL* 500+ approx. 50...500 mS and greater
Industrial wastewater (select the sensor according to the electrical conductivity of the medium)			
	Disinfectants (chlorinated media)		
	Table salt solution		
Alcohol	Rinsing agents		
Marmalade	Milk / buttermilk / yogurt		
De-ionized water	Fruit juice		
Mineral oils	Coolant / lubricants		Ketchup/mayonnaise/mustard
Plant oils	Formic acid (30%)		Phosphoric acid (10%)
Ammonia (30%)	Vinegar		Sulfuric acid (10%)
Drinking water	Cola		Calcium chloride (30%)
Sugar solution diluted	Honey / glue (water base)	Blood	Hydrochloric acid (40%)
Toothpaste	Beer	Saltwater	Nitric acid (12%)

Application Examples

Wafer processing (semiconductor industry)

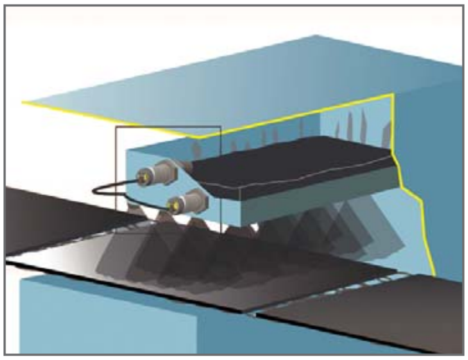
During wafer processing, SmartLevel monitors the overflow of hydrochloric acid through a container wall so that it can be exposed to condensate containing salt. The highly conductive deposit of the condensate, however, does not impede it.



Wafer processing

Cold deformation
(oil spraying system in special machine design)

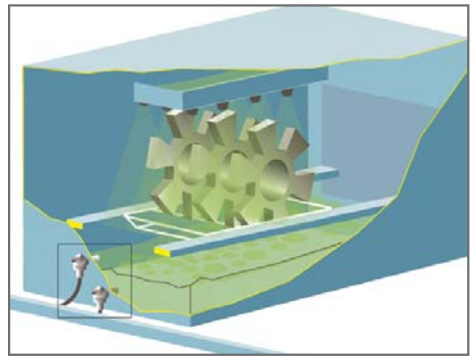
Likewise, the SmartLevel ignores highly conductive graphite deposits when it reliably measures the level of an oil-graphite mixture through the wall of a plastic container in special machine construction. Through this, it is ensured that the mixture can be continuously sprayed on metal plates, to allow for bending during cold deformation.



Cold deformation

Cleaning metal parts
(industrial cleaning technology)

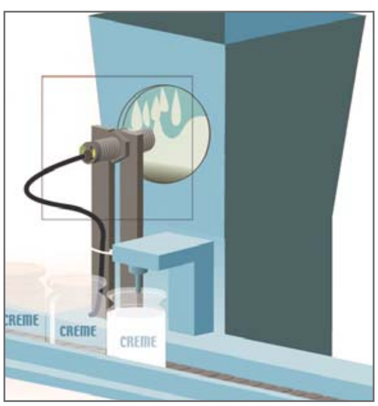
SmartLevel controls the fill level of a supply tank for cleaning metal parts, because it can compensate for foam, grease and filming. Water spray and temperatures up to 105 °C do not impede it. In addition, its PTFE sleeve protects it from aggressive media.



Industrial cleaning technology

Filling bottles of body lotion (packaging industry)

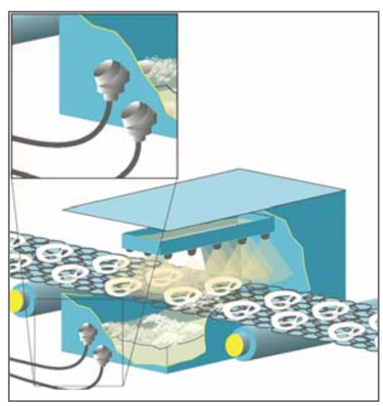
The SmartLevel is suited for detecting conductive, paste-type media, which can cause heavier deposits. Therefore, it is ideally used during filling of bottles of body lotion. Through a 10 mm-thick inspection glass, it monitors their fill level in stainless steel containers with absolute reliability and, through its external positioning, also reduces the effort for cleaning.



Packaging industry

Brining pretzels (food industry)

SmartLevel also finds use directly in foaming media. For example, in the stainless steel container of a system in which pretzels are sprayed with caustic soda lye. In doing so, it controls the minimum-maximum fill level of the caustic soda lye with absolute reliability.



Food industry

Balluff offers the most extensive capacitive product line with over 25 years of high quality manufacturing and engineering experience. Balluff has a long, proven history of providing dependable, robust sensing technologies for the most challenging applications found in science and industry. This is reflected in the development and release of SmartLevel enhanced capacitive sensing technology.

For more information, visit www.balluff.us/smartlevel

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